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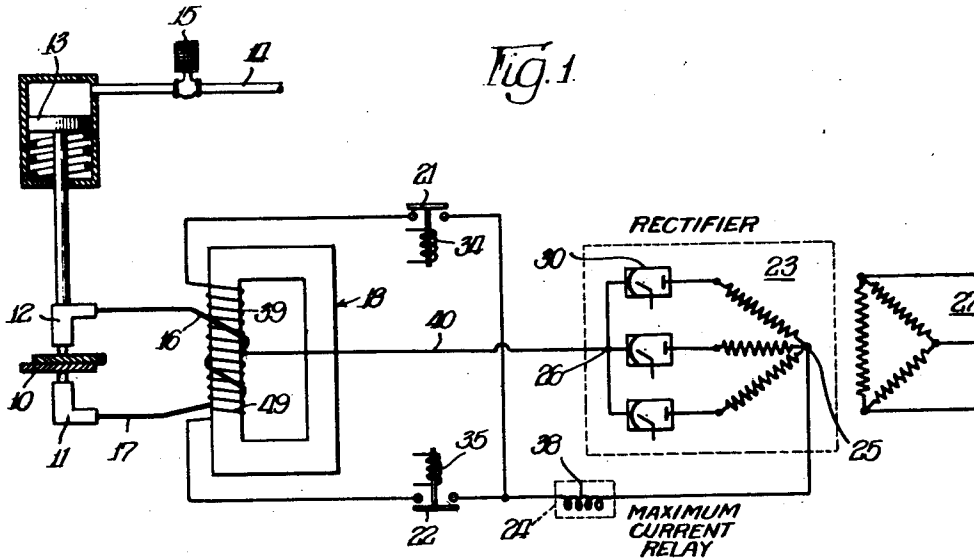
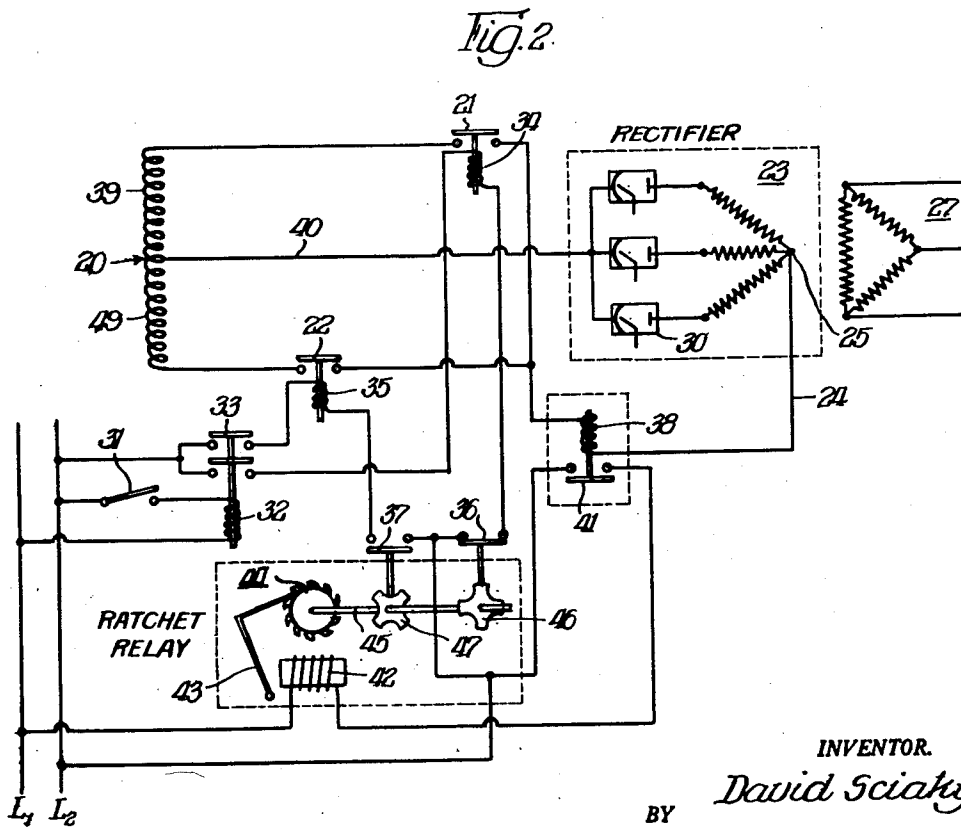
D. SCIACKY

2,415,708

WELDING METHOD AND APPARATUS THEREFOR

Filed June 23, 1944

5 Sheets-Sheet 1



INVENTOR.

BY *David Sciacky,*

Wilkinson Hubley Byron & Knight
ATTORNEYS

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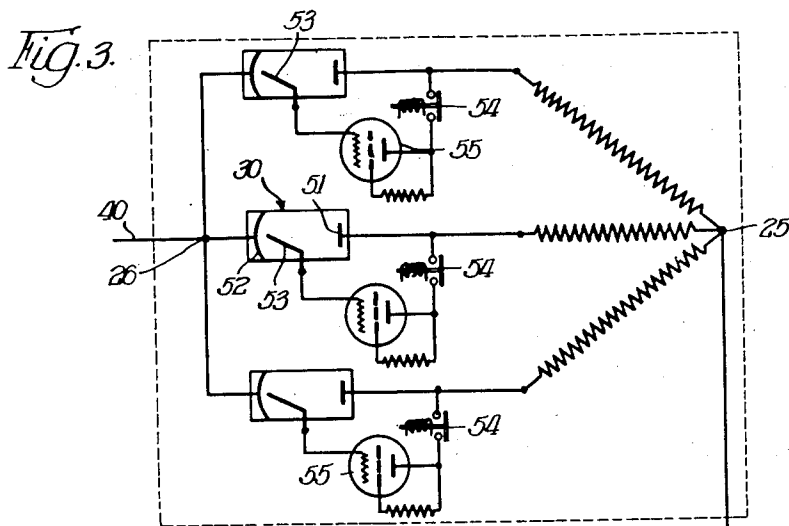
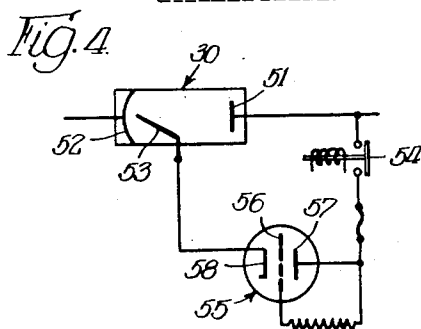
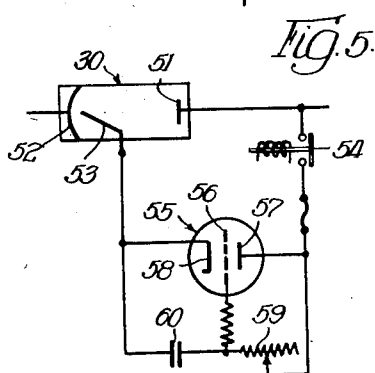
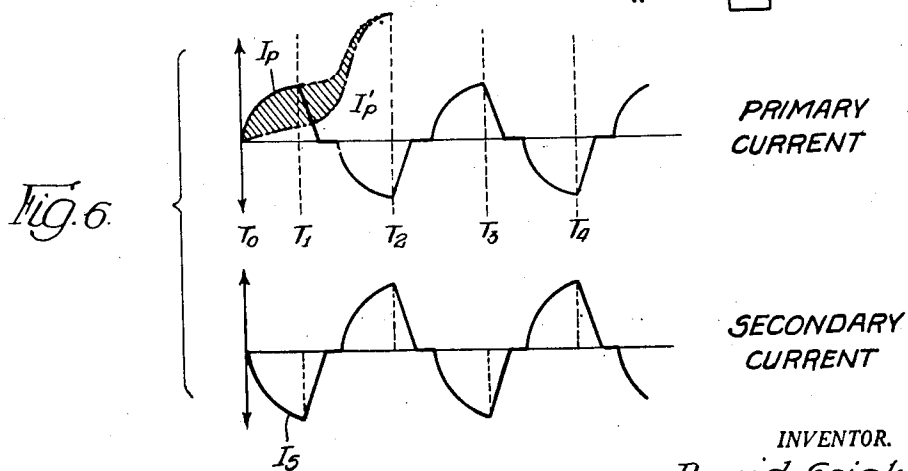
D. SCIACKY

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WELDING METHOD AND APPARATUS THEREFOR

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5 Sheets-Sheet 2



INVENTOR.
David Sciacky,
BY

Wilkinson Hubby Ogden & Knight
ATTORNEYS

Feb. 11, 1947.

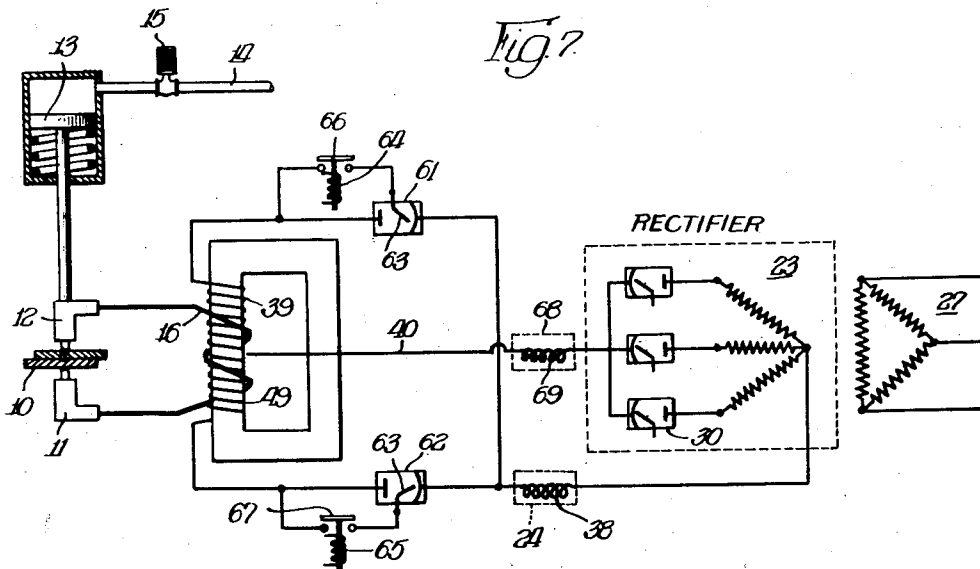
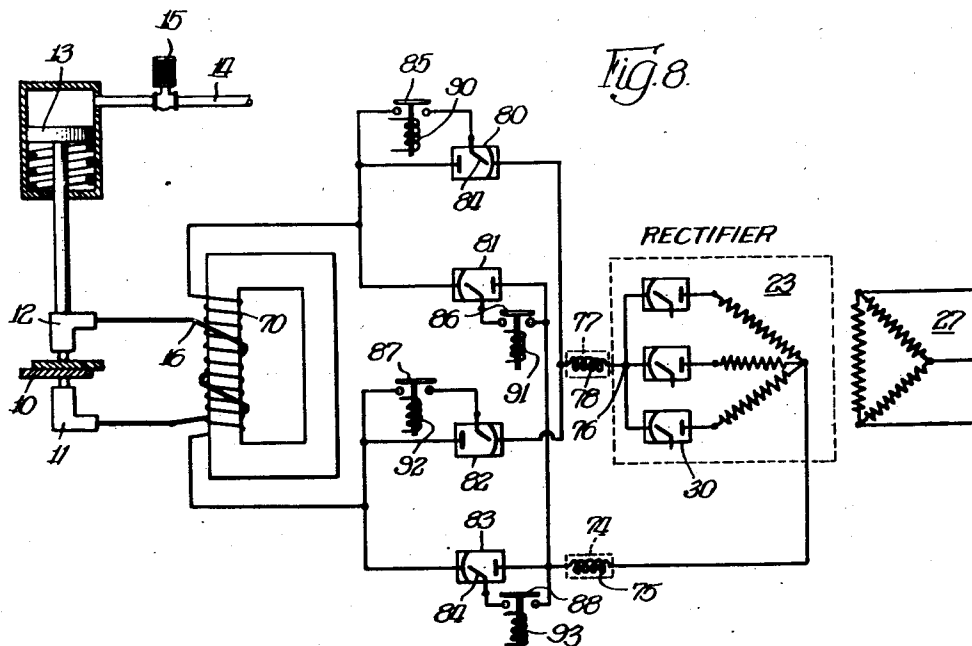
D. SCIAKY

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WELDING METHOD AND APPARATUS THEREFOR

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Feb. 11, 1947.

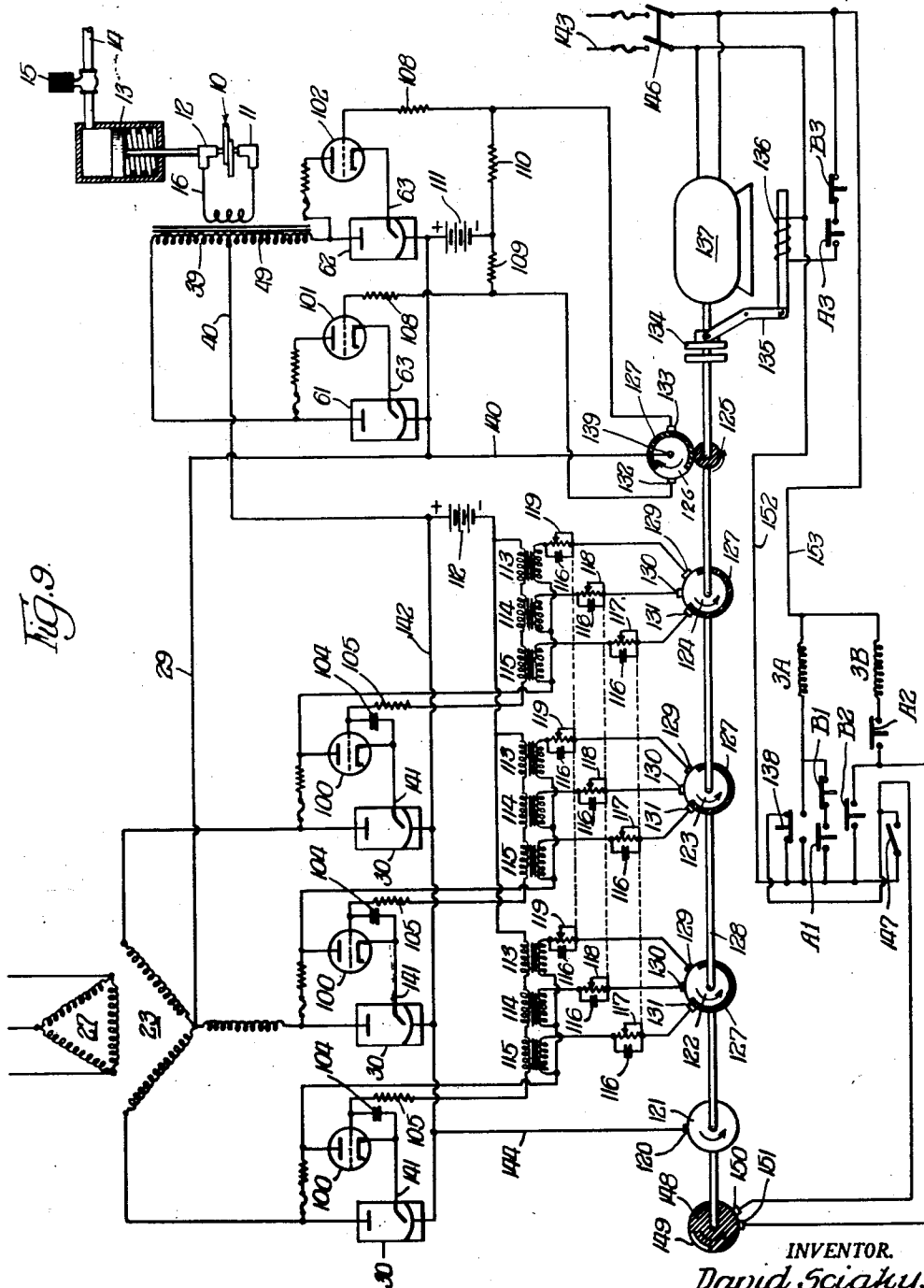
D. SCIAKY

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WELDING METHOD AND APPARATUS THEREFOR

Filed June 23, 1944

5 Sheets-Sheet 4



INVENTOR.

David Sciaky,

BY

Wilkinson Hubby Byron & Knight
attys

Feb. 11, 1947.

D. SCIACKY

2,415,708

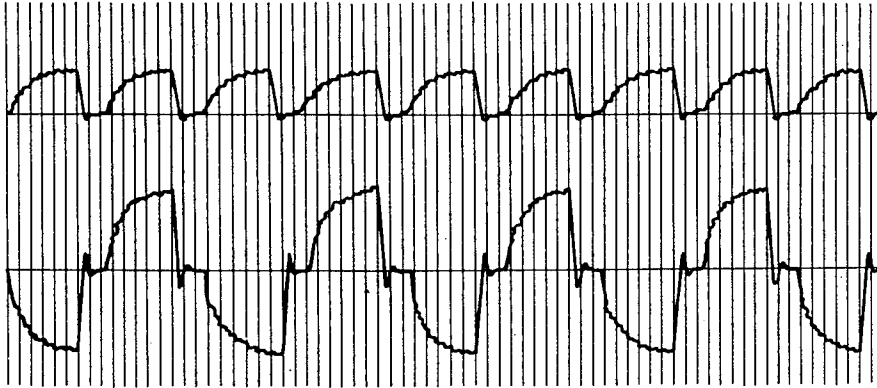
WELDING METHOD AND APPARATUS THEREFOR

Filed June 23, 1944

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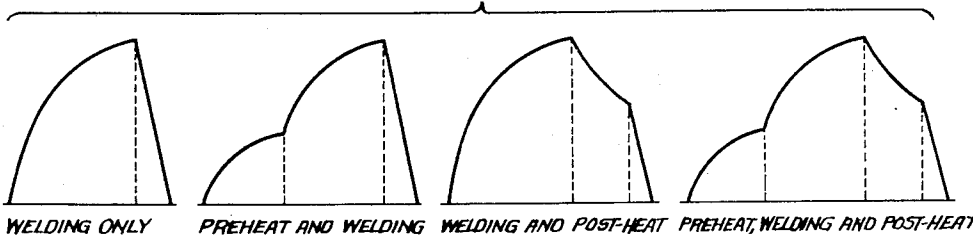
Fig. 12.

PRIMARY CURRENT



SECONDARY CURRENT

Fig. 10.



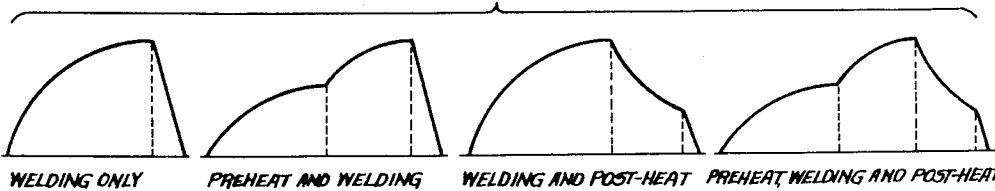
WELDING ONLY

PREHEAT AND WELDING

WELDING AND POST-HEAT

PREHEAT, WELDING AND POST-HEAT

Fig. 11.



WELDING ONLY

PREHEAT AND WELDING

WELDING AND POST-HEAT

PREHEAT, WELDING AND POST-HEAT

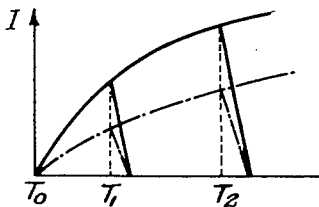


Fig. 13.

INVENTOR.

David Sciacky,

BY

William H. H. Byrne & Knight
ATTY.

UNITED STATES PATENT OFFICE

2,415,708

WELDING METHOD AND APPARATUS
THEREFORDavid Sciaky, Chicago, Ill., assignor to Welding
Research, Inc., Chicago, Ill., a corporation of
Illinois

Application June 23, 1944, Serial No. 541,708

22 Claims. (Cl. 219-4)

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The invention relates generally to the art of electric welding and has reference more particularly to a method and apparatus for the resistance welding of metals whereby any single impulse of welding current or multiple impulses are wave shaped to best suit the characteristics of the metal being welded and wherein a balanced load will be drawn from a multiple-phase alternating current supply line.

Conventional systems of welding by the application of sixty-cycle alternating current to the welding electrodes are inefficient in many respects and therefore unsatisfactory. Aside from the fact that the power demand is high, due to a low power factor, and that the welding load unbalances three-phase supply lines, the wave form is not of a shape best suited for producing high quality welds with any degree of efficiency. The rise to the peak during the first half-cycle is so rapid that fusion occurs before the metal has been heated sufficiently between sheet and electrode to insure uniform contact. The result is excessive pick-up on the electrodes and a tendency toward irregular shaped welds. Also because the nature of the material is such that although complete fusion may be obtained after the first half-cycle, porosity within the slug will result if the flow of current is stopped abruptly. It is necessary, therefore, to maintain the heat in the weld a longer time by increasing the duration of current flow. This means that the surrounding metal is excessively heated, which results in a detrimental effect on the heat-treat properties, causes warping and increases tip pick-up.

It has been long realized that certain wave forms of welding current were superior to sixty-cycle alternating current for the resistance welding of metals. All prior devices for producing waves of a different shape, however, have been limited to one, or at best, a slight variation of one wave form. The welding system of the invention is a material improvement in this respect since the present apparatus is capable of adjustment so that the wave-shape of the welding current may be varied to any number of combinations. As will be seen from Figure 13, any desired magnitude of welding current, within the limits of the device, may be obtained after any given time. Conversely, any given value of welding current may be obtained after any desired time of current flow.

More specifically, the present system of welding is capable of producing a preheat current, a welding current, and a post-heat current for each

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welding impulse in any combination of magnitude and time relationship to each other.

Another feature of the improved welding system resides in the fact that there is no reversal of direction of the current flow during any one impulse. In other words, the preheat, welding and postheat currents all merge into each other with no reversal of direction or instantaneous drop in magnitude.

By the application of a welding current of the type herein explained to metal sheets for the purpose of welding said sheets, the electrode tips will be caused to come into intimate contact with the surface of the metal because of the comparatively slow rise to the peak. The addition of a preheat current also improves this condition still further. It is to be stressed that the shape of the current may be controlled to almost desired form but the same always rises slowly to its peak. After said peak has been reached the current may then be dropped to zero abruptly or caused to fall slowly to zero along most any desired wave form. Control of this postheat current enables the use of shorter times for the welding current than would be required without its use. This is accomplished because the weld is caused to slowly instead of having all heat removed at once.

In view of the foregoing, an object of the invention resides in the provision of welding apparatus having an improved mode of operation whereby the current impulse for each welding operation may be wave-shaped to best suit the characteristics of the metal being welded.

Another and more specific object of the invention resides in the provision of a welding system capable of wave-shaping the welding current for each operation to produce a preheat current, a welding current and a postheat current in any desired combinations of magnitude and time relationship with each other.

A further object is to provide welding apparatus for the resistance welding of metals wherein the wave-shape of the welding current may be varied and wherein a balanced load may be drawn from a multiple-phase alternating current supply.

In the present system of welding successive impulses of direct current are applied to the primary winding of a welding transformer. However, the direction of current flow for each impulse is reversed with the desired result that a longer application of the voltage for each impulse is possible without saturating the iron core of the transformer.

Accordingly, another object of the invention is

to provide a welding system wherein welding is effected by means of a low frequency alternating current in the secondary circuit produced by flowing successive impulses of direct current through the primary winding of the welding transformer, and in reversing the direction of current flow through said primary winding for each impulse.

With these and various other objects in view, the invention may consist of certain novel features of construction and operation as will be more fully described and particularly pointed out in the specification, drawings and claims appended hereto.

In the drawings which illustrate an embodiment of the device and wherein like reference characters are used to designate like parts—

Figure 1 is a diagrammatic view illustrating apparatus for welding having a mode of operation coming within the invention;

Figure 2 is a wiring diagram illustrating means for reversing the successive current impulses to the primary of the welding transformer;

Figure 3 is a diagrammatic view illustrating one form of rectifier employing ignitrons and which provides for voltage control of the direct current impulses applied to the primary of the transformer;

Figure 4 is a wiring diagram showing one method of firing the ignitron tubes of the rectifier;

Figure 5 is a wiring diagram illustrating another method whereby delayed firing of the ignitrons may be effected;

Figure 6 illustrates diagrammatically the current flowing in the primary winding for successive impulses and the induced alternating current flowing in the secondary circuit;

Figure 7 is a diagrammatic view illustrating a modification coming within the invention;

Figure 8 is a diagrammatic view illustrating still another modification coming within the invention;

Figure 9 is a diagrammatic view illustrating a complete welding system including a phase-shifting circuit to obtain preheat, welding and postheat currents for each welding operation;

Figure 10 illustrates graphically current curves plotted against time for different welding operations, some including preheating and postheating periods;

Figure 11 illustrates graphically current curves similar to Figure 10 but wherein the peak amplitude and duration of the preheating and postheating periods have been changed;

Figure 12 is a reproduction of an actual oscillograph of currents obtained in a welding operation by the method of the invention; and

Figure 13 is a diagram illustrating the manner of wave-shaping an impulse of welding current by variations in the voltage and frequency.

Referring to the form of the invention shown in Figure 1, the workpiece 10 to be welded is placed between the stationary electrode 11 and the movable electrode 12 of the welding machine. Pneumatic pressure is applied to the piston 13 from the air line 14 through operation of valve 15, thereby causing the workpiece to be placed under mechanical pressure between electrodes 11 and 12 which are electrically connected to the secondary winding 16. Said winding and the connections to the electrodes constitute the secondary circuit 17 of the welding transformer identified in its entirety by numeral 18. The primary winding 20 is electrically connected through contactors 21 and 22 with a rectifier 23.

One end of the primary circuit, including the maximum current relay 24, is connected to the rectifier at a neutral point 25 and the other end of said primary circuit is connected to the rectifier as at 26. The source of current for said rectifier 23 is identified by numeral 27, the same comprising a conventional three-phase alternating current supply. The rectifier 23 includes ignitrons 30 for voltage control, which will be more particularly described as the description proceeds.

When the contactors 31 and 32 are closed and opened successively the current from the three-phase alternating current supply 27 will pass through the rectifier 23 and the resulting direct current will thereupon flow through the primary winding 20. Each closing and opening of the contactors produces an impulse of direct current which flows through the primary winding 20. The successive direct current impulses will induce an alternating current in the secondary circuit which will flow through the electrodes 11 and 12 and through the workpiece 10 to effect a welding of the metal parts.

The wiring diagram of Figure 2 illustrates means for actuating the contactors so that they make and break the primary circuit in rapid succession and which also reverses the current flow through the primary winding on each impulse. The switch 31 in series with coil 32 is connected across a source of current supply indicated by L_1-L_2 . The closing of the switch energizes coil 32 and causes the double contactor 33 to close. This energizes either coil 34 or 35, depending on whether contactor 36 or contactor 37 is closed, it being observed that contactor 36 is in series with coil 34 and that contactor 37 is in series with coil 35 and that each series connection of coil and contactor is connected in parallel across the current supply L_1-L_2 . As shown in Figure 2, contactor 36 is closed and thus coil 34 will be energized to cause contactor 21 to close. As a result current will flow through part of the primary circuit including the maximum current relay comprising coil 38, the contactor 21 and the upper half 39 of the primary winding 20, returning to the rectifier by conductor 40.

When the current impulse flowing downwardly through the upper half 39 of the primary winding reaches a predetermined value, coil 38 of the maximum current relay is energized and contactor 41 is caused to close. Said contactor and the coil 42, in series therewith, is connected across the current supply lines L_1-L_2 . Immediately upon the closing of contactor 41, coil 42 is energized and the arm 43 of the ratchet relay is actuated to effect rotation of ratchet 44 and shaft 45 fixed thereto. Cams 46 and 47 are also fixed to shaft 45 and disposed under the contactors 36 and 37, respectively. Thus actuation of the ratchet relay will effect opening of contactor 36 and closing of contactor 37. Coil 34 is accordingly de-energized and coil 35 is energized to now cause contactor 22 to close. Immediately following the opening of contactor 21, coil 38 of the maximum current relay becomes de-energized and arm 43 of the ratchet relay assumes its initial position. The flow of current in the primary is reversed since the current will now flow through contactor 22 and upwardly through the lower half 49 of the primary winding, returning to the rectifier by the common conductor 40, center tapped to the primary winding.

This impulse of direct current flowing through the primary winding in a reverse direction from that of the preceding impulse is allowed to reach

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the same predetermined value measured by the maximum current relay which eventually becomes energized, causing contactor 41 to close, energizing coil 42, and actuating the ratchet relay in a manner as before. This next actuation of the ratchet relay will change the position of the cams so as to cause opening of contactor 37 and closing of contactor 36. Contactor 22 opens and contactor 21 again closes to cause the next succeeding impulse of direct current to flow through said contactor, downwardly through the upper half 39 of the primary winding, and through conductor 40 back to the rectifier.

Successive impulses of direct current are thus supplied to the primary of the welding transformer as long as the operator maintains switch 31 in closed position and in accordance with the invention the direction of current flow through the primary is reversed for each impulse. This action of reversing the current flow has the effect of nullifying whatever magnetism might remain in the iron core. It also permits a longer application of the voltage for each impulse without the possibility of saturating the iron core of the transformer.

Figure 6 shows the magnetizing current I_p as a function of time, the same resulting from the application of a direct current voltage to the primary when the secondary circuit is open. The curve I_p shows the variation in the primary current when the secondary is closed. From T_0 to T_1 the primary current builds up until a maximum value is reached at time T_1 , whereupon the maximum current relay is actuated to interrupt the primary current which accordingly decays exponentially. The curve I_s shows the induced welding current. If, for example, the primary current were interrupted at a time T_2 the said current would have reached a very high value. It is important, according to the present invention, to interrupt the current at time T_1 since interruption will therefore take place before the iron core of the transformer is saturated. As a result the storing of excessive energy is avoided and the appearance of an over-voltage at the instant of interruption is eliminated. By using an iron core of correct dimensions made of iron of high permeability it is possible to apply the voltage over a substantial period of time without incurring saturation. Figure 6 also illustrates successive applications of direct current impulses to the primary winding of the transformer to obtain an alternating secondary current and which can be used for welding heavy stock requiring a relatively long heating time.

Figure 12 is an actual oscillograph of the primary and secondary currents obtained in a welding operation. The primary current is shown as successive positive impulses. This is correct since the oscillograph shows the primary current in the return conductor 40 and each impulse of current is of course flowing in the same direction. This distinguishes from Figure 6 which diagrammatically illustrates current flowing through the primary winding 20, whereas, one impulse is in one direction and the next impulse is in a reverse direction. The secondary current is a low frequency alternating current with positive and negative surges of substantially equal magnitude. The number of cycles of secondary current which determine the total welding time, depending on the thickness and characteristics of the metal to be welded, can be controlled by means of a timer.

The rectifier is shown in detail in Figure 3.

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With such a rectifier it is possible to modify the wave shape of the secondary current since the voltage of the direct current impulses can be varied. For this purpose the rectifier employs ignitron tubes indicated by numeral 30, each tube including an anode 51, a mercury cathode 52 and a firing pin 53. The circuit from the anode to the cathode through the tube is non-conducting until the mercury is vaporized. The mercury is vaporized by firing pin 53 which extends into the tube having contact with mercury cathode. When the circuit through the firing pin is closed by closing contactor 54, current will flow through the thermionic control tube 55 to the firing pin, with the result that the mercury in the ignitron tube is immediately vaporized and current then flows from anode 51 to cathode 52. Current will flow in this direction only for the positive half cycle of the alternating current supply. When the negative half cycle is reached the ignitron tube ceases to be conducting and the same operation is repeated on the next positive half cycle provided contactor 54 remains closed.

The circuit for control tube 55, which operates to deliver full voltage from the ignitrons, is shown in Figure 4. In this circuit grid 56 is connected directly to the plate 57 and has the same polarity as the plate. The cathode 58 is connected to firing pin 53. The control tube thus passes current immediately at the beginning of a positive half cycle of alternating current. Therefore the ignitron tube becomes conducting at the very beginning of each positive half cycle of the alternating current supply and accordingly full voltage is obtained in the rectified current output.

In Figure 5 the grid 56 of the control tube is connected to plate 57 through a variable resistor 59 and said grid is connected to the cathode through condenser 60. When the contactor 54 is closed the control tube does not pass current immediately to the cathode since the grid remains at a negative potential with respect to the plate for a certain period. The setting of the variable resistor 59 controls the length of this period before the grid becomes positive enough to permit current to flow through the control tube and to thus fire the ignitron. The longer the delay in firing effected by control tube 55, the less of each positive half cycle is passed by the ignitron and thus the voltage of the rectified current is correspondingly lower.

The modification of the invention shown in Figure 7 has the same mode of operation as explained in connection with Figure 1 and the modification is structurally the same with the exception that ignitrons are substituted for the contactors. The ignitron tube 61 is substituted for the contactor 21 and ignitron tube 62 is substituted for contactor 22, as shown and described in connection with Figure 1. Each ignitron tube is provided with a firing pin 63 and coils 64 and 65 are associated with contactors 66 and 67 which function to make and break the circuit through the firing pin by means of which the ignitrons are controlled. The maximum current relay 24, having the coil 38, is employed as described in Figure 1 to determine the duration of the primary current impulses, and the minimum current relay 68 having coil 69 is employed to reverse the current flow.

The modification of Figure 7 operates as follows. The workpiece 10 is placed between the stationary electrode 11 and the movable elec-

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trode 12. Pneumatic pressure is applied to piston 13 from air line 14 through operation of valve 15, thereby causing the workpiece to be put under mechanical pressure between electrodes 11 and 12 which are connected to the secondary winding 16. The primary winding is center tapped to provide the connection for the common conductor 40 and the upper half 39 of said primary winding is connected in series with ignitron tube 61 whereas, the lower half 49 of the primary winding is connected in series with the ignitron tube 62.

When contactor 66 is closed the ignitron tube 61 will become conductive upon the flow of current. Then by firing the ignitrons 30 of the rectifier a balanced load is drawn from the alternating current supply line 27, converted to direct current by the rectifier and passed through tube 61 to the upper winding 39 of the primary. The tubes 30 in the rectifier are interrupted when a predetermined current value is reached, measured by the maximum current relay including coil 38. The direct current flowing in the primary circuit therefore dies out and this constitutes one impulse of current. When a predetermined minimum value of current is reached, the value at which tube 61 is no longer conductive, the minimum current relay including coil 69 operates to open the contactor 66 preventing tube 61 from becoming conductive again and causing contactor 67 to close. The closing of contactor 67 conditions tube 62 for conduction and when the ignitrons of the rectifier are again fired the next impulse of direct current will flow through tube 62 and through the winding 49 of the primary. This second impulse, however, has been reversed in direction with respect to the first impulse. Tubes 61 and 62 thus alternate in operation which reverses the magnetic field that is built up in the iron core of the transformer each time. This reversal prevents saturation of the iron core from impairing the effectiveness of each succeeding impulse.

In the modification of Figure 8 each direct current impulse is caused to flow through the entire primary winding and at the same time the current flow is reversed for each impulse. Therefore in this modification the primary winding is not center tapped. Four ignitron tubes are connected in the primary circuit, which circuit includes the primary winding 70. The rectifier 72 is the same as previously described, having a connection at 73 with one terminal of the primary circuit in series with the maximum current relay 74 having coil 75. The other terminal of the primary circuit is connected to the rectifier at 76, this connection including the minimum current relay 77 having coil 78.

The modification of Figure 8 differs from that of Figure 7 in the use of four ignitron tubes identified by numerals 80, 81, 82 and 83, each including a firing pin 84 connected in series with a contactor 85, 86, 87 and 88, respectively. When the contactor of its particular tube is closed the ignitron is rendered conductive, provided current is supplied by the rectifier 23.

When coils 90 and 93 are energized the contactors 85 and 88 associated therewith are caused to close and the tubes 80 and 83 are conditioned for operation. Then by firing the tubes in the rectifier a balanced load is drawn from the multiple phase alternating current supply and passed through the rectifier to be supplied to the primary circuit as direct current. The same will flow through tubes 80 and 83 and through

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the primary winding 70. By interrupting the tubes in the rectifier at a predetermined current value, controlled by the maximum current relay 74 the current flow is stopped. When a minimum value of current is reached, the value at which tubes 80 and 83 are no longer conductive, the minimum current relay operates to open contactors 85 and 88 and simultaneously closes contactors 86 and 87 by energizing coils 91 and 92. Tubes 81 and 82 are thereby conditioned for operation. When the tubes of the rectifier are again fired the next impulse of direct current will flow through tubes 81 and 82 and through the primary winding 70. This time, however, it will be observed that the current flows through the primary winding in a direction reverse to that of the first impulse. The maximum current relay operates as before to interrupt the supply of current from the rectifier when a predetermined value is reached and when a minimum value is reached the minimum current relay operates to open contactors 86 and 87 and to again close contactors 85 and 88 so that the operation above described is repeated. The two sets of tubes 80, 83 and 81, 82 thus alternate in passing current which reverses the magnetic field built up in the transformer for each impulse.

The reversing of the direct current impulses has the additional advantage of nullifying any residual magnetism which might remain in the iron core, thereby permitting a longer application of the voltage for each impulse without saturating the iron core of the transformer. The amplitude of the secondary current surges can be controlled by adjustment of the voltage of the primary current impulses as described in connection with Figures 3, 4 and 5. It will be observed that two impulses of primary current are required to induce one cycle of alternating secondary current, or, in other words, the frequency of the reversing primary current, Figure 6, is the same as that of the induced secondary current.

The frequency can be controlled by regulating the frequency of the primary impulses. In Figures 1 and 2 the frequency of the primary impulses are determined by the characteristics of the circuit, since coil 42 has a time constant as well as the coil of the maximum current relay. In Figures 7 and 8 the frequency of the primary impulses are controlled by a timer electrically connected to the contactors of the rectifier and which thus regulates the firing of the ignition tubes of said rectifier. Thus the induced alternating current in the welding circuit may have a frequency ranging from less than 1 to approximately 30 cycles per second.

Figure 9 illustrates diagrammatically a form of phase-shifting control for the ignitrons of the rectifier whereby a preheating current, a welding current and a postheating current may be produced for each welding operation to thereby generate different values and durations of heat for application to the weld according to the characteristics of the particular metal being welded. In the form of control herein shown for illustrating this feature of the present invention the ignitrons 30 of the rectifier are controlled by thyatrons 100 which are normally held non-conductive by a negative grid bias in a manner to be presently described. However, by rendering the thyatrons conductive for the purpose of firing the ignitrons at predetermined times in the positive half cycles of the alternating supply voltage different values of secondary current are

produced and almost any combination as regards duration and magnitude of the preheating, welding and postheating currents may be obtained.

Referring more particularly to Figure 9, the main welding circuit is similar to that disclosed in Figure 7 and where identical elements are employed the same reference characters will indicate like parts. Said welding circuit consists of the conductor 29 which joins the neutral point of the secondary winding 23 of the transformer with the ignitron tubes 61 and 62, the conductors which connect the plates of the ignitrons with the welding transformer primary 39 and 49, the return line 40 having connection with the cathodes of the ignitrons 30 of the rectifier, and through said tubes back to the secondary winding 23 of the transformer. In operation current flows in the above path alternately through the ignitron tubes 61 and 62 and at the same time the ignitron tubes 30 of the rectifier are made alternately conductive and non-conductive. This causes a direct current impulse to pass through the primary winding 39 of the welding transformer and then through primary winding 49 of said transformer to induce a current in the secondary 16, which flows alternately first in one direction and then in the other.

The firing of the ignitrons 30 is controlled by the thyratrons 100 and the firing of ignitrons 61 and 62 is controlled by the thyratrons 101 and 102. In the non-firing condition the thyratrons 100 are maintained non-conductive by the negative grid bias in the form of the battery 112. The positive side of the battery is connected by conductor 142 to the cathodes of the rectifiers 30, the circuit being completed by the firing pins 141 connecting with the cathodes of the thyratrons 100. The negative side of the battery is connected to the grids of the thyratrons 100 through the series connected secondaries of the transformers 113, 114 and 115 and the current limiting resistors 105. The transformers 113, 114 and 115 have no effect in this condition as their primaries are not connected to any source of voltage, as will be clearly understood as the description proceeds. Condensers 104 between the cathode and grid of tubes 100 are present merely to by-pass any transients which may occur.

Thyratrons 101 and 102 are held non-conductive by means of the negative grid bias in the form of a battery 111. The positive side of the battery is connected to the cathodes of the ignitron tubes 61 and 62 and through said tubes the circuit includes the igniters 63 and the cathodes of the thyratrons 101 and 102. The grids of said thyratrons are connected to the negative side of said battery through the resistors 108, 109 and 108, 110, respectively. Both batteries 111 and 112 are made just sufficiently negative to prevent firing of the thyratrons 100, 101 and 102 during positive half cycles of plate voltage with a suitable margin of safety.

As previously explained, the firing of ignitrons 30 is accomplished by causing the grids of the thyratrons 100 to become positive at a predetermined time in the positive half cycles of the alternating-current voltage appearing across the tubes.

Transformers 113, 114 and 115 are peaking transformers, that is, the secondary voltage appears as a series of alternately positive and negative peaks of the same frequency as the alternating-current voltage applied to the primary. As regards the control of Figure 9, the applied primary voltage is the sine wave alternating cur-

rent appearing across the tubes 100. There are three sets of transformers, one for each ignitron and the primaries of each set are connected across their corresponding thyatron tube 100, cathode to plate circuit, it being understood that the connection is alternately made and broken, as will be described later.

The alternating current voltage applied to the primary windings of the transformers 113, 114 and 115 may be shifted in phase with respect to the cathode-plate voltage of the tubes 100 by means of the phase shift means 116-117, 116-118 and 116-119. The constants of these circuits are such that varying the resistances 117, 118 and 119 produces only a shift in the phase relationship and not the magnitude of the applied voltage. Therefore, it will be understood that as the resistances 117, 118 and 119 are varied the positive peaks produced by the secondaries of the transformers 113, 114 and 115 are caused to occur at different times in the positive half cycles of voltage appearing across tubes 100. These secondary peaks are of sufficient magnitude to more than overcome the negative grid bias of the battery 112. Therefore, the tubes 100 may be caused to fire at any point by means of the positive peaks appearing on their grids.

Motor 137 is connected to an electrical supply line 143 through the manually actuated switch 146 and said motor is of such nature that its speed is constant. A shaft 128 formed of any suitable metal so as to comprise an electrical conductor has the contact members 121, 122, 123 and 124, the driving gear 125, and the cam 148 non-rotatably mounted thereon. Said shaft 128 is mechanically connected to the motor 137 through clutch 134. Closing of the foot switch 128 energizes coil 136 and through sequencing mechanism to be described later causes linkage 135 to operate clutch 134 and thereby effect rotation of shaft 128 at the same speed as motor 137. The operation of the apparatus is such that whenever clutch 134 is disengaged the contact members 122, 123 and 124 will be so positioned that the electrical contact brushes 129, 130 and 131 will be in engagement with the insulated section 127 of the contact members, respectively.

When clutch 134 is engaged the shaft 128 is rotated in the direction indicated and as a result brushes 129 are caused to come in contact with the conductor section of the contact members 122, 123 and 124. At this point the electrical connection is complete between the primaries of the transformers 113 and the tubes 100. The circuit is as follows. The cathodes of tubes 100 are connected to one side of the primaries 113 through igniters 141, conductors 142 and 144, brush 120, contact member 121, shaft 128, contact members 122, 123, 124, brushes 129, condensers 116, and resistors 119. The other side of the primaries is connected directly to the plate of tubes 100. Accordingly, the tubes 100 and consequently igniters 300 will fire at the point where the positive secondary peak occurs in each positive half wave appearing across the tubes 100.

At the same time the ignitron 61 will fire because the grid of the thyatron 101 has become neutral with respect to the cathode. The circuit is as follows. The cathode of tube 101 will be connected through the igniter 63, conductor 140, shaft 139, the contact member 126 keyed to said shaft, brush 132, which at this time will have contact with the conductor section of contact member 126, and finally resistor 108 connecting

with the grid of said thyatron 101. Therefore instead of the grid being connected to the negative side of the battery 111, the said grid is neutralized with respect to its cathode and firing of the thyatron takes place to in turn fire the ignitron 61, which initiates flow of direct current through the primary winding 39 of the welding transformer, the said current returning by the return conductor 40. It will be understood that contact member 126 is driven at half speed from shaft 128 by means of the gear 125. During the period when brush 132 is in contact with the conductor section of said member 126, it will be understood that the grid of thyatron 102 will be connected to the negative side of battery 111 since brush 133 will be in contact with the insulated section 127 of the contact member.

As shaft 128 continues its rotation brushes 130 and then brushes 131 will come in contact with the conductor section of contact members 122, 123 and 124. This in turn will produce secondary positive peaks in the transformers 114 and 115, causing the same to appear on the grids of tubes 100 during each positive half cycle of plate voltage. As shaft 128 continues its rotation brushes 129 will eventually come into contact with the insulated section 127 of contact members 122, 123 and 124 and following this action the brushes 130 will contact said insulated section and finally brushes 131. The secondary peaks in the transformers 113, 114 and 115 will thus disappear and tubes 100 are again maintained non-conductive by the negative grid bias 112.

The next revolution of shaft 128 causes the above described action to be repeated except that contact member 126, which rotates at one-half speed of shaft 128, will have electrical contact with brush 133, neutralizing the grid of thyatron 102 whereby the ignitron 62 will fire, this time to cause the direct current impulse to flow through primary winding 49.

As regards the control apparatus above described, one typical mode of operation of the contact members for producing peak voltages in the secondaries of the transformers 113, 114 and 115 would be to have the peak of transformer 113 occur late in the positive half cycle of plate voltage on tubes 100 so that the voltage appearing across primary winding 39 or 49 of the welding transformer is low, producing a low secondary or preheating current which rises slowly for preheating the weld. The peak voltages produced in the secondaries of transformers 114 would appear early in the positive half cycles on tubes 100 to provide a high voltage input to the welding transformer primary and a corresponding high secondary current having a much faster rise to thereby form the welding current. Finally the peak voltages produced by transformers 115 would be caused to appear late in the positive half cycles of voltage on the plate of tubes 100, causing a lower voltage across the welding transformer primary, which in turn causes the secondary current to fall off from the welding peak to some lower value, thus constituting a post-heating current.

By adjusting the speed of rotation of shaft 128, the length of the conductor section of the contact members 122, 123 and 124 and the spacing between the brushes 129, 130 and 131 almost any combination as regards duration and magnitude of preheat, weld and postheating currents may be obtained. Operation may be such that for each time foot switch 138 is closed one revolution of shaft 128 is obtained. Single weld-

ing impulses are accordingly produced and which may be wave-shaped as herein described and fully disclosed in Figures 10 and 11. In Figure 10 the peak welding current is the same for all four illustrations. In Figure 11 the peak welding current is considerably lower and the duration of the preheating and postheating periods has been increased. Almost any combination of peak welding current and duration of preheating and postheating periods may be obtained by the present invention to best suit the particular characteristics of the metal being welded.

It is also possible with the form of control shown in Figure 9 to effect continuous rotation of shaft 128 at a constant speed as long as the foot switch 138 remains closed. When the control operates in this manner successive welding impulses are produced, the welding current flowing first in one direction and then in another to comprise a low frequency alternating current and wherein each impulse may be wave-shaped as above described.

For single impulse operation the switch 147 is permanently closed. When the foot switch 138 is moved to down position the relay coil 3A becomes energized since the same is connected across the supply source 143. The normally open contact A1 of relay 3A closes, locking the relay in the energized position, whether or not the switch 138 remains in down position. Contact A3 of the relay also closes, energizing the solenoid coil 136. This in turn moves actuating mechanism 135 to close clutch 134 and shaft 128 thereupon rotates in the direction indicated at constant speed to cause firing of the ignitrons of the rectifier as described.

Immediately after the insulated section 127 of contact members 122, 123 and 124 has passed under contact brush 131 conductor section 149 of cam 148 completes the circuit between contact brushes 150 and 151. Relay 3B becomes energized at this point through the circuit between conductors 152 and 153 consisting of closed switch 147, brush 150, conductor section 149 of cam 148, brush 151, and the closed contact A2 of relay 3A. The normally closed contact B3 of relay 3B opens, deenergizing coil 136, releasing mechanism 135 to disengage clutch 134. The friction of the low inertia shaft 128 causes it to stop rotation instantly. At this time the brushes 129, 130 and 131 are in contact with the insulated section 127 of the contact members 122, 123 and 124. As conductor section 149 is very short it may have rotated slightly past contacts 150 and 151 by the time the shaft 128 comes to rest. Relay 3B is held energized, however, through contact B2, which closes when the relay is energized. If initiating switch 138 is held in down position during the whole operation the sequence is locked until said switch is released. As soon as this action takes place relay 3A becomes deenergized because normally closed contact B1 was opened as soon as relay 3B was energized. Contact A2 is also opened, causing relay 3B to become deenergized. Contact A3 is opened and contact B3 is closed in that order so that the solenoid coil 136 remains deenergized. Reclosing of the foot switch 138 causes a complete sequence of operation as above described to be repeated, thereby producing another impulse of welding current.

For repeat operations the switch 147 is left open. Closing of the foot switch 138 in the down position energizes relay 3A which closes contact A1, locking said relay in the energized position.

Contact A3 closes, causing the solenoid coil 136 to become energized, moving actuating mechanism 135 to close clutch 134 and starting rotation of shaft 128 in the same manner as described above for a single impulse operation. This time, however, when brushes 150 and 151 are electrically connected to the conductor section 149 of the cam 148, the relay 3B will not become energized as long as switch 138 is held in a down position because the circuit between lines 152 and 153 will not be complete, switch 147 being open. Accordingly, shaft 128 will continue to rotate at constant speed, causing a repetition of current impulses to the welding transformer as long as switch 138 is held in down position. To stop the operation, switch 138 is released or moved to an up position. Then as soon as contactor section 149 of cam 148 makes contact with brushes 150 and 151 the relay 3B will become energized. The circuit is complete then from line 152 through the upper contacts of switch 138, through brushes 150, 151, conductor section 149, the closed contact A2, through relay 3B to line 153. Energizing of relay 3B then causes contact B3 to open, which deenergizes the solenoid coil 136, causing clutch 134 to be released. The shaft 128 thereupon stops rotation in the same manner as described with respect to a single impulse operation so that brushes 129, 130 and 131 are all in contact with an insulated section 127. Energizing of 3B also causes contact B1 to open, deenergizing relay 3A. This causes contact A2 to open which in turn deenergizes relay 3B and the control is then ready for another sequence of operations. Contact B2 in the circuit of relay 3B serves as a lock-in contact for said relay so that deenergizing of 3A must always precede deenergizing of 3B and also to hold relay 3B energized as long as contact A2 is closed regardless of the action of cam 148.

Aside from the above advantages to be gained from welding by the use of the apparatus of the invention, an additional and important consideration resides in the saving in power over that required in the operation of single phase, sixty-cycle welding machines. In said machines the inductance of the secondary circuit of the welding transformer is of such magnitude that the power factor is lowered considerably which causes a large amount of wasted energy. The supply to the present apparatus is from a three-phase line and an equal amount of power is drawn from all three phases.

Referring to Figure 13, welding impulses are shown having current peaks of different values and different periods of duration. Any desired magnitude of welding current within the maximum and minimum limits of the apparatus may be obtained after any given period of time such as times T₁ or T₂. Conversely, any given value of welding current may be obtained after any desired time of current flow. This is not possible with conventional alternating current since said current always reaches its maximum after one-fourth of a cycle. In the case of sixty-cycle current the maximum would be reached in .0415 second. For time T₁ the welding impulses of the present apparatus may have a high value of current, represented by the full line or a lower value of current, represented by the dot and dash line and the same for time T₂. The desired shape of the welding impulse is obtained by selecting a particular voltage for the direct current flowing through the primary winding of the transforming means and by controlling its duration or pe-

riod of flow. Voltage control of the direct current impulses is effected by control of the ignitrons of the rectifier, as previously described, or by means of a tap switch on either the welding transformer or on the rectifier transformer.

The invention is not to be limited to or by details of construction of the particular embodiment thereof illustrated by the drawings, as various other forms of the device will of course be apparent to those skilled in the art without departing from the spirit of the invention or the scope of the claims.

What is claimed is:

1. A method of electric welding whereby a balanced load is drawn from a multi-phase alternating current supply, which consists in rectifying said alternating supply current to direct current, applying impulses of said direct current in continuing succession to the primary winding of a welding transformer, controlling the magnitude and duration of each direct current impulse, reversing the direction of current flow through the primary winding on each impulse, to thereby induce an alternating current in the secondary circuit of the welding transformer, and flowing said alternating current through the workpiece to weld the same.

2. A method of electric welding whereby a balanced load is drawn from a multi-phase alternating current supply, which consists in rectifying said alternating supply current to direct current, applying impulses of said direct current in continuing succession to the primary winding of a welding transformer, controlling the magnitude and duration of each direct current impulse, reversing the direction of current flow through the primary winding on each impulse, to thereby induce in the secondary circuit of the welding transformer an alternating current having a frequency proportional to the number of direct current impulses per second and which may range from less than 1 to 30 cycles per second, and flowing said low frequency alternating current through the workpiece to weld the same.

3. A method of electric welding, which consists in rectifying an alternating supply current to direct current, applying impulses of said direct current to the primary winding of a welding transformer to thereby induce impulses of welding current in the secondary circuit, and in varying the voltage of the direct current applied to the primary winding during each impulse in a controlled manner, whereby the resulting welding current for each impulse produces a controlled heating effect and which may be predetermined to best suit the characteristics of the metal being welded.

4. A method of electric welding which consists in supplying direct current to the primary winding of a welding transformer for a controlled period of time, whereby an impulse of welding current is induced in the secondary circuit of said transformer, and in regulating the voltage of said direct current to apply to said primary winding an initial current of low voltage and then a current at a higher voltage, whereby the welding current has an initial preheating period followed by a welding period.

5. A method of electric welding which consists in supplying direct current to the primary winding of a welding transformer for a controlled period of time, whereby an impulse of welding current is induced in the secondary circuit of said transformer and in regulating the voltage of said direct current to apply to said primary winding

an initial current of low voltage, then a current at a predetermined maximum voltage, and finally a current of lower voltage, whereby the welding current has an initial preheating period followed by a welding period and finally a post-heating period.

6. A method of electric welding which consists in supplying direct current to the primary winding of a welding transformer for a controlled period of time, whereby an impulse of welding current is induced in the secondary circuit of said transformer, regulating the voltage of said direct current to apply to said primary winding an initial current of low voltage and then a current at a higher voltage, whereby the welding current has an initial preheating period followed by a welding period, and in controlling the duration of said preheating and welding periods by controlling the time of application of said initial low voltage current and the higher voltage current.

7. A method of electric welding which consists in supplying direct current to the primary winding of a welding transformer for a controlled period of time, whereby an impulse of welding current is induced in the secondary circuit of said transformer, regulating the voltage of said direct current to apply to said primary winding an initial current of low voltage, then a current at a predetermined maximum voltage and finally a current of lower voltage, whereby the welding current has an initial preheating period followed by a welding period and finally a post heating period, and in controlling the duration of said preheating, welding and postheating periods by controlling the time of application of said low voltage, maximum voltage and lower voltage currents.

8. A method of electric welding which consists in applying successive impulses of direct current to the primary winding of a welding transformer, reversing the direction of current flow through the primary winding on each impulse to thereby induce in the secondary circuit of the welding transformer an alternating current having a frequency equal to one-half the number of direct current impulses per second, and in automatically regulating the voltage of said direct current for each impulse to apply an initial current of low voltage and then a current at a predetermined maximum voltage, whereby each half cycle of welding current has an initial preheating period followed by a welding period.

9. Apparatus for the electric resistance welding of metals, a source of poly-phase alternating current, a welding transformer having a primary winding and a secondary load circuit, an electric discharge valve for each phase having a series connection in circuit with said primary winding, said valves each having ignition control including a control circuit for firing said valves to render them conductive to pass current during the positive half cycles of the alternating E. M. F. impressed thereon, whereby an impulse of direct current may be supplied to the primary winding to induce an impulse of welding current in the secondary load circuit, phase shift means included in the control circuit for each valve for predetermining the instants in the positive half cycles at which the valves are fired, and means for controlling the duration of said direct current flow to the primary winding for each impulse.

10. Apparatus for the electric resistance welding of metals, a source of poly-phase alternating current, a welding transformer having a primary winding and a secondary load circuit, an electric

discharge valve for each phase having a series connection in circuit with said primary winding, said valves each having ignition control including a control circuit for firing said valves to render them conductive to pass current during the positive half cycles of the alternating E. M. F. impressed thereon, whereby an impulse of direct current may be supplied to the primary winding to induce an impulse of welding current in the secondary load circuit, means having operation to condition the control circuits for starting and ending the period during which the valves are fired thereby controlling the duration of said direct current flow to the primary winding for each impulse, and phase shift means for regulating the voltage of the direct current during flow thereof, said means having location in the control circuit for each valve and predetermining the instants in the positive half cycles at which the valves are fired.

11. In combination, a poly-phase alternating current supply, transforming means having a primary circuit and a secondary load circuit, an electric valve for each phase of the alternating current supply having a series connection with its respective phase and the primary circuit, said electric valves being of the arc discharge type and having a control electrode for rendering the valves conducting so that they transmit the positive half cycles of said supply current to the primary circuit causing an impulse of current to flow through the primary winding of said transforming means, means in the form of a biasing potential for maintaining the electric valves non-conducting, control means for each valve including peaking transformers capable of producing secondary peak voltages sufficient to overcome the biasing potential and rendering the electric valve conducting, phase shift means in the primary circuits of said peaking transformers for varying the instants in the positive half cycles at which the secondary peak voltages occur to thereby control the voltage of the current transmitted by the electric valve to the primary circuit, and means also having associated relation with the primary circuits of the peaking transformers for conditioning said primary circuits to thereby control the duration of the period during which said valves are conductive.

12. In combination, a poly-phase alternating current supply, transforming means having a primary circuit and a secondary load circuit, an electric valve for each phase of the alternating current supply having a series connection with its respective phase and the primary circuit, said electric valves being of the arc discharge type and having a control electrode, a control circuit for the electrode of each valve for firing the valves to render them conducting for transmitting the positive half cycles of said supply current to the primary circuit causing an impulse of current to flow through the primary winding of said transforming means, each control circuit including a thermionic tube having a grid element, means in the form of a biasing potential electrically connecting with said grid elements for maintaining said tubes non-conductive whereby the discharge valves are likewise maintained non-conductive, a plurality of peaking transformers for each thermionic tube capable of producing secondary peak voltages sufficient to overcome the biasing potential whereby said thermionic tube becomes conductive to fire its discharge valve, the grid element of each thermionic tube electrically connecting with said biasing potential

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through the secondary windings of its respective peaking transformers, phase shift means in the primary circuit of each peaking transformer for predetermining the instants in the positive half cycles at which the secondary peak voltages occur to thereby control the voltage of the current transmitted by the electric valves to the primary circuit, and means having associated relation with said primary circuits of the peaking transformers for conditioning said primary circuits to thereby control the duration of the period during which said valves are conductive.

13. A method of electric welding which consists in applying impulses of direct current in continuing succession to the primary winding of a welding transformer, reversing the direction of current flow through the primary winding on each impulse to thereby induce an alternating current in the secondary circuit having a frequency proportional to the number of direct current impulses per second, predetermining the wave shape of the alternating secondary current within limits by selecting a particular voltage and a particular frequency for the direct current impulses, and flowing said alternating current through the workpiece to weld the same.

14. A method of electric welding which consists in applying impulses of direct current in continuing succession to the primary winding of a welding transformer, reversing the direction of current flow through the primary winding on each impulse to thereby induce an alternating current in the secondary circuit having a frequency equal to one-half the number of direct current impulses per second, selecting a particular voltage and a particular frequency for the direct current impulses to secure a wave shape in the alternating secondary current best suited to the characteristics of the metal being welded, and flowing said alternating current through the workpiece to weld the same.

15. A method of electric welding which consists in applying impulses of direct current to the primary winding of a welding transformer to thereby induce impulses of welding current in the secondary circuit, controlling the magnitude of the welding current for each impulse and controlling the duration of each impulse independently of its magnitude.

16. Apparatus for the electric resistance welding of metals, a source of polyphase alternating current, a welding transformer having a primary winding and providing a secondary load circuit, a transformer-type rectifier electrically connected to said alternating current source, said rectifier including at least one electric discharge valve for each phase having a series connection in circuit with said primary winding, said valves each having ignition control comprising a control circuit, said control circuit when energized rendering said discharge valves conducting to cause direct current to flow through the primary winding, means for terminating said current flow following a predetermined time interval by rendering the valves non-conducting, and other means included in said control circuit for regulating the voltage of said current.

17. Apparatus for the electric resistance welding of metals, a source of polyphase alternating current, a welding transformer having a primary circuit and providing a secondary load circuit, a transformer-type rectifier electrically connected to said alternating current source, said rectifier including at least one electric discharge valve for each phase having a series connection in cir-

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cuit with said primary winding, said valves each having a control electrode, a control circuit for the electrode of each valve, said control circuit when energized firing the valves to render them conducting to cause direct current to flow through the primary winding, means for terminating said current flow by rendering each valve non-conducting, said means being adjustable whereby the duration of current flow is controlled, and other adjustable means included in said control circuits for regulating the voltage of said current.

18. Apparatus for the electric resistance welding of metals, in combination, a source of polyphase alternating current, a welding transformer having a primary winding and a secondary load circuit, a primary circuit electrically connecting with said primary winding, a transformer-type rectifier for connecting said primary circuit to the source of polyphase alternating current, said transformer-type rectifier having primary and secondary windings with one terminal of the primary circuit connected to a neutral point on the secondary windings and an electric discharge valve for each phase connecting the secondary windings, respectively, with the other terminal of the primary circuit, a control circuit for the electric discharge valves for rendering the valves conducting when the circuit is energized whereby direct current is supplied to the primary circuit, means for rendering the valves non-conducting to thereby interrupt said current following a predetermined impulse of current flow through the primary winding of said welding transformer, other electric discharge valves in the primary circuit for reversing the direction of current flow through the primary winding on each impulse, and means in the primary circuit responsive to a predetermined minimum current for controlling said other electric discharge valves.

19. Apparatus for the electric resistance welding of metals, in combination, a source of polyphase alternating current, a welding transformer having a primary winding and a secondary load circuit, a primary circuit electrically connecting with said primary winding, a transformer-type rectifier for connecting said primary circuit to the source of polyphase alternating current, said transformer-type rectifier having primary and secondary windings with one terminal of the primary circuit connected to a neutral point on the secondary windings and an electric discharge valve for each phase connecting the secondary windings, respectively, with the other terminal of the primary circuit, a control circuit for the electric discharge valves for rendering the valves conducting when the circuit is energized whereby direct current is supplied to the primary circuit, a maximum current relay in the primary circuit responsive to a predetermined maximum current for rendering the valves non-conducting to thereby interrupt said current following an impulse of current flow through the primary winding of said welding transformer, other electric discharge valves in the primary circuit for reversing the direction of current flow through the primary winding on each impulse, and a minimum current relay in the primary circuit responsive to a predetermined minimum current for controlling said other electric discharge valves.

20. Apparatus for the electric resistance welding of metals, in combination, a source of polyphase alternating current, a welding transformer having a primary winding and a secondary load circuit, a primary circuit electrically connecting with said primary winding, a transformer-type

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rectifier for connecting said primary circuit to the source of polyphase alternating current, said transformer-type rectifier having primary and secondary windings with one terminal of the primary circuit connected to a neutral point on the secondary windings and an electric discharge valve for each phase connecting the secondary windings, respectively, with the other terminal of the primary circuit, a control circuit for the electric discharge valves for rendering the valves conducting when the circuit is energized whereby direct current is supplied to the primary circuit, means for rendering the valves non-conducting to thereby interrupt said current following a predetermined impulse of current flow through the primary winding of said welding transformer, other electric discharge valves in the primary circuit for determining the direction of current flow in said circuit, a control circuit for each said other electric discharge valve for rendering the valves conducting whereby they pass said direct current, and means controlling said control circuits for reversing the direction of current flow to the primary winding on each impulse.

21. Apparatus for the electric resistance welding of metals, a source of polyphase alternating current, a welding transformer having a primary winding and providing a secondary load circuit, a primary circuit including said primary winding which has a series relation therewith, rectifying means connected to said alternating current source on its in-put side and having its out-put side electrically connected to the primary circuit for rectifying said alternating current and supplying successive impulses of direct current to the primary winding, electric discharge valves in said primary circuit for reversing the direction of current flow to the primary winding on each impulse, and a minimum current relay in the primary circuit for controlling the firing of said discharge valves to prevent a certain valve

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from becoming conductive before a certain other of said discharge valves has ceased to pass current.

22. Apparatus for the electric resistance welding of metals, a source of polyphase alternating current, a welding transformer having a primary winding and providing a secondary load circuit, a primary circuit including said primary winding which has a series relation therewith, a transformer-type rectifier connected to said alternating current source on its in-put side and having its out-put side electrically connected to the primary circuit, whereby said poly-phase alternating current is rectified and supplied as direct current to the primary circuit, said transformer-type rectifier having operation to supply said direct current in successive impulses to the primary circuit and which are thus caused to flow through the primary winding, electric discharge valves in the primary circuit for reversing the direction of current flow to the primary winding on each impulse, and a minimum current relay in the primary circuit for controlling each impulse of current flow to prevent an impulse from flowing through the primary winding before the current of the preceding impulse has reached a predetermined minimum value.

DAVID SCIACKY.

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Certificate of Correction

Patent No. 2,415,708.

February 11, 1947.

DAVID SCIACKY

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Column 2, line 27, before the word "slowly" insert *cool*; and that said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 13th day of May, A. D. 1947.

[SEAL]

LESLIE FRAZER,
First Assistant Commissioner of Patents.